

NASA Satellite Servicing Study

Improved Robotic Enablers for Satellite Servicing

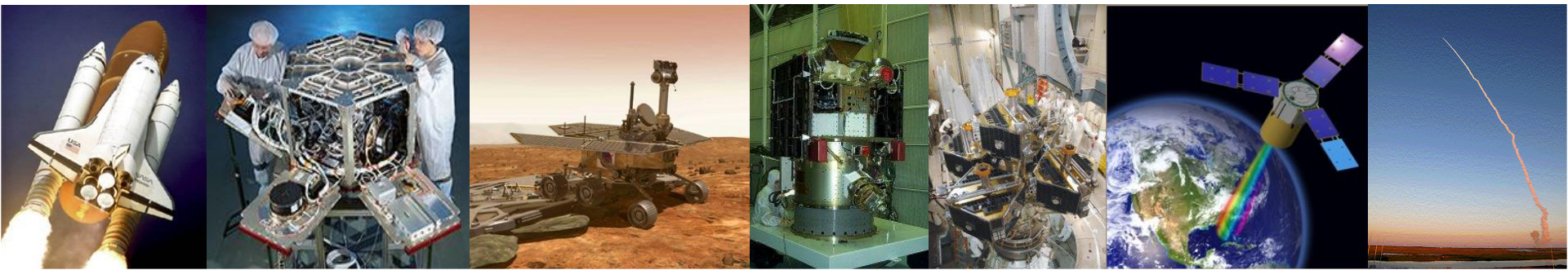
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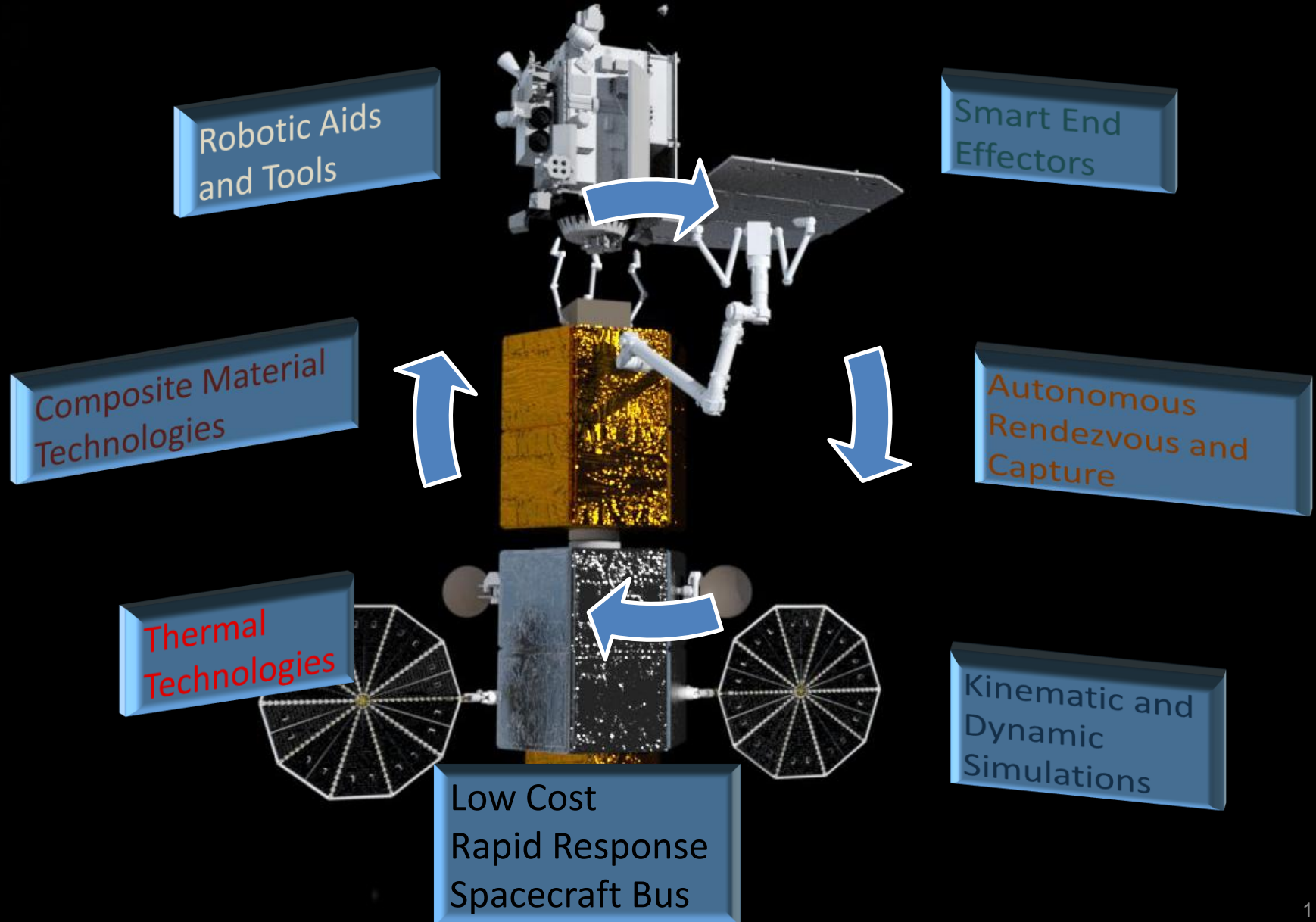
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Improved Robotic Enablers for Satellite Servicing



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Robotic Aids and Tools

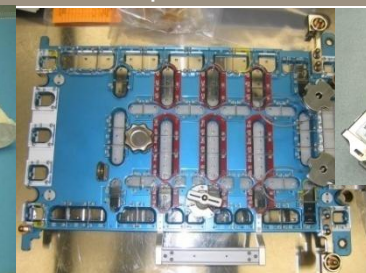


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Improved Robotic Tools provide capability to perform unique and complex tasks

Heritage from Manned Servicing Support:

- Hubble Servicing Missions Crew Aids and Tools
- ISS Crew Aids and Tools
- Perform complex tasks not originally designed for servicing

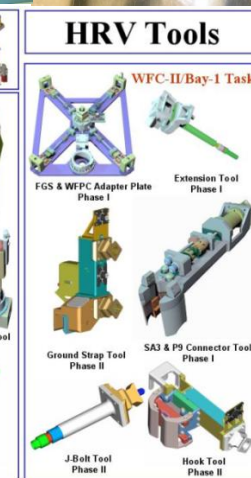


Hubble Robotic Servicing and De-Orbit Mission

- Tool Designs to PDR
- Interfaces and function with SPDM
- Perform tasks not originally designed for robotic servicing

ISS DTO for Refueling

- Tool Designs and development in work
- Allows for On-Orbit Refueling or other fluid transfer
- Testing in orbit with existing robot and flexibility in tasking
- Increase TRL level



Future Robotic Tool Designs

- Spacecraft Capture and Docking Mechanism
- Lubrication, Harness Management
- Thermal Blanket Repair or Replacement
- Improved electronics box level replacement and card changeout
- Small or stuck fastener removal, retention and replacement

Safety Cap Tool



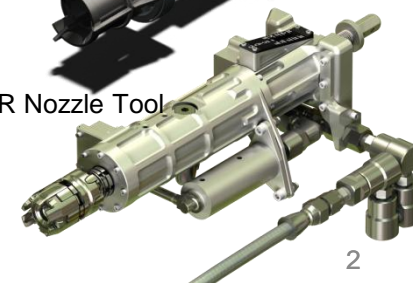
Tertiary Cap Tool



Wire Cutter Tool



EVR Nozzle Tool



End Effector Design for vision, proximity assessment, and tool interfaces, to more efficiently perform capture and servicing activities

Mechanical Interface

to provide attachment of multiple tools and provide drive capability for rotation or translation

Electrical Interface

Provide electrical connectivity to tool when needed

Stereo Cameras

Controllable to synchronize with attached tool interface to spacecraft



Grab Tool

to interface to common satellite exposed structures

Lights

LEDs to provide lighting conditions and avoid shadows

LADAR

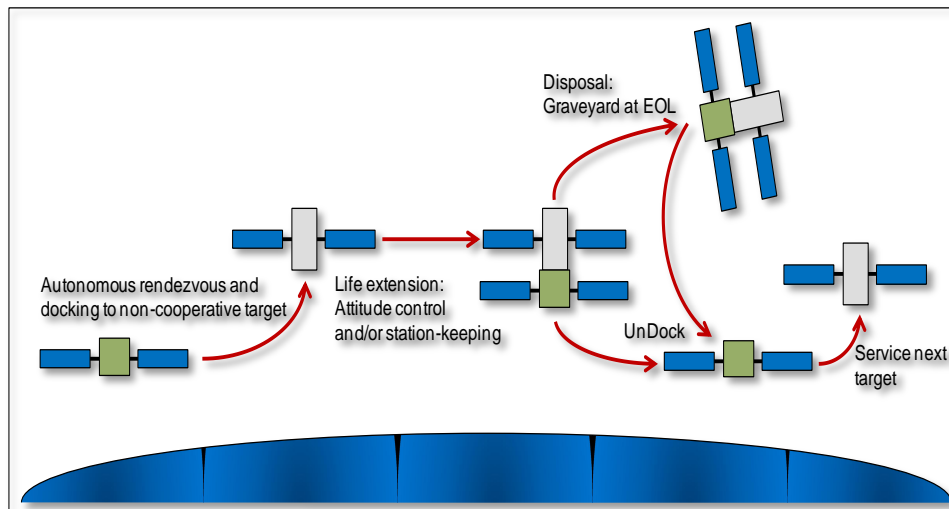
to determine distance between end effector and spacecraft interface

Autonomous Rendezvous and Capture

AR&C requires advanced sensors and on-board processing for both long range rendezvous and final capture

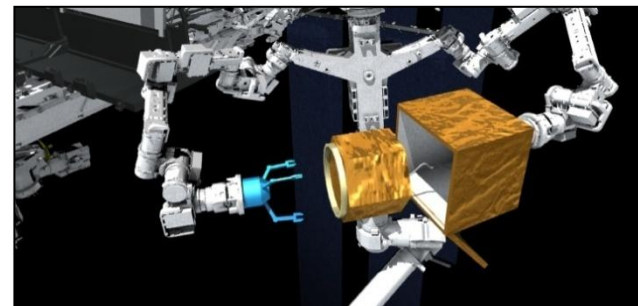
Technologies exist to perform simple, non-manipulative servicing missions today

- Autonomous target location & tracking
 - Applications from space-based, space situational awareness
- Autonomous approach and docking
 - Reliable sensor technologies: 2D & 3D vision, Ladar, etc...
 - Demonstrated docking hardware: Robotic arms, "stingers", etc...



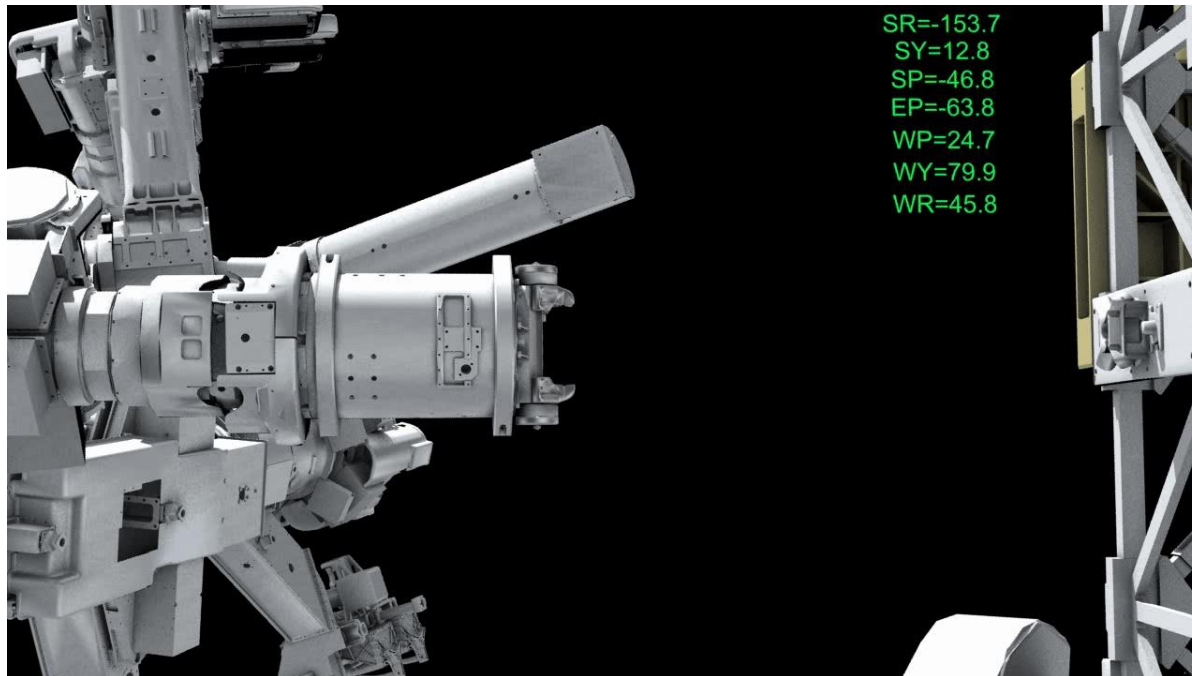
Near term developments will facilitate the most challenging missions

- Space debris detection & orbit determination
- Tumbling capture
 - Advanced sensor fusion/processing
 - Advanced robotic end-effector and tool development
- Robotic Servicing of cooperative and non-cooperative targets



Provides Testing and training Capabilities to prepare for On-Orbit Conditions

- Improved real time kinematic simulations with clearance assessments, joint angles, realistic lighting and shadows
 - Training tools for operators
 - Vision System verification
- Leverage motion capture to transfer 6DOF ground testing results to on-orbit simulations
- Developing near real time dynamic simulations including visualization
 - Motion created by combined robotic systems flexibilities and contact dynamics
 - Motion caused by servicing platform attitude control adjustments
 - Motion caused by serviced spacecraft due to its inertia or combined vehicles connectivity.



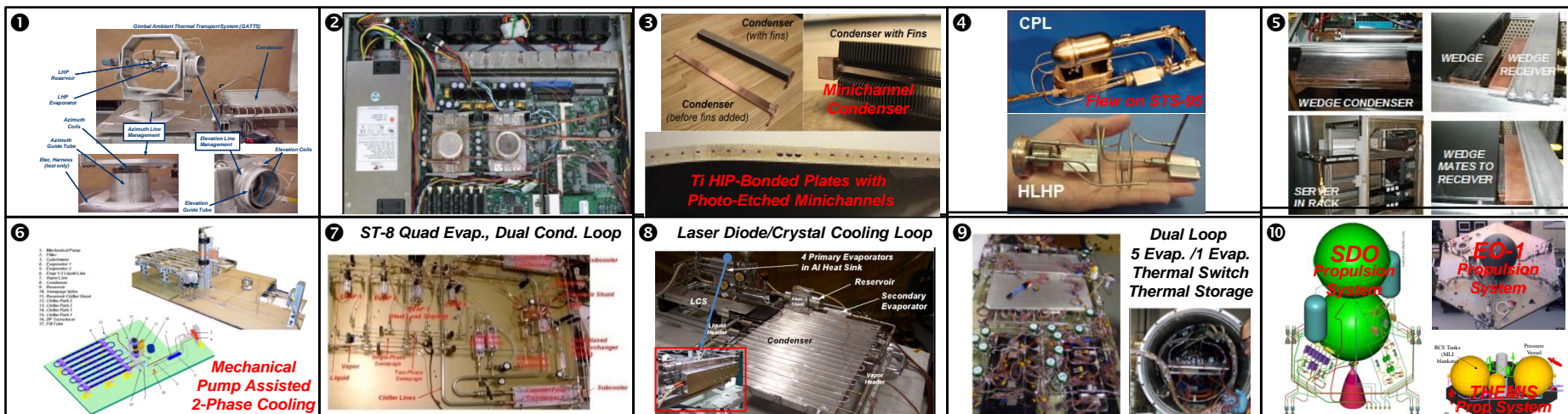
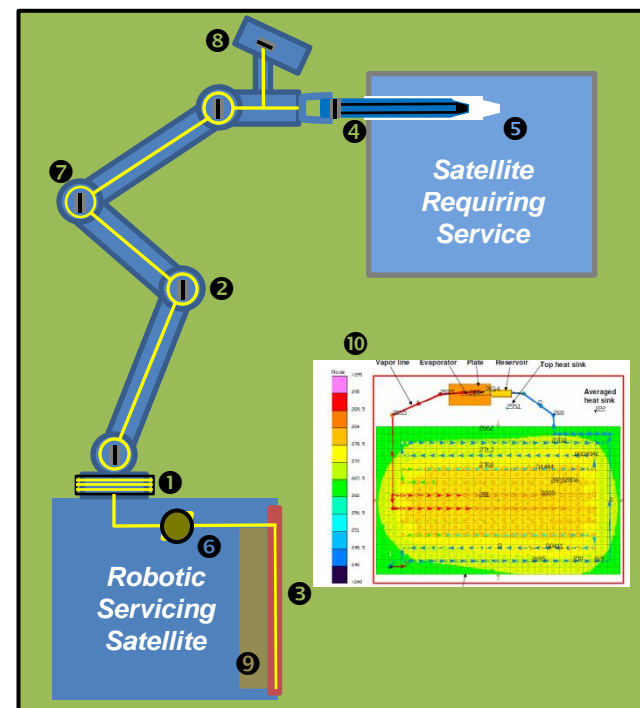
Thermal Control of Robotic Servicing Satellites



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Improved environmental conditions for robotic systems

1. Across-Gimbal Cooling Systems ... compact cooling of robot arm motors
2. Microchannel Evaporators ... compact packaging of motor/electronics cooling
3. Minichannel Condensers/Exchangers ... compact packaging of motor/electronics cooling
4. Miniaturized Two-Phase Loops ... compact packaging of motor/electronics cooling
5. Wedge Thermal Interface ... robotic replacement of satellite components
6. Hybrid Mechanical/Capillary Systems ... ground testable extended length robot arms
7. Multiple Evaporator/Condenser Loops ... efficient multi-motor/electronics cooling
8. Laser Cooling System Architectures ... high flux light source/camera/electronics cooling
9. Thermal Transport/Switching/Storage ... extended operation in severe environments
10. SINDA/FLUINT Thermal-Fluid Modeling ... design, simulation, optimization



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Composite Material Technologies



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Provides lightweight, smart structures

Complex parts

- Replace current metal components such as tools
- Advanced Materials
 - Ceramic Matrix Composites (CMCs)
 - Nano-particulate filled resin systems for improved compression strength and fracture toughness

Embedded Sensors

- Provides force feedback at or near the interface
- Provides environmental condition information
 - Thermal
 - Vibration
 - Radiation
 - Electrical Conductivity

Embedded Conductors

- Allows transfer of data
- electronics built into the structure

Embedded Damping

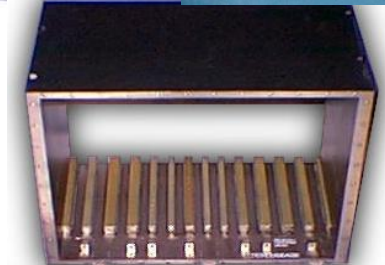
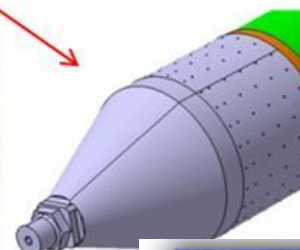
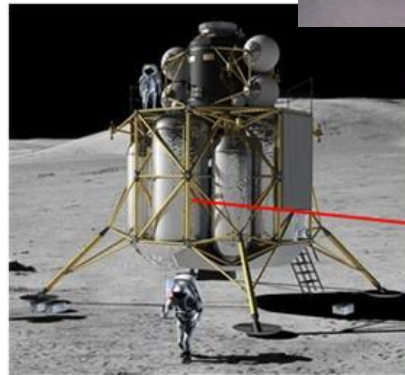
- Improved dynamic behavior

End Fitting Damping

- Active
- Passive

Radiation Protection for Cameras and Electronics

- Material has radiation transfer inhibitors built in
- Maintain strength and stiffness characteristics



Summary

- Experience developing tools and technologies to assist with servicing
- Foundations exist to develop applicable technologies
- Similar technologies developed previously that can be leveraged
- Technologies work with each other to accomplish satellite servicing goals:
 - ❑ Tools to enhance servicing capabilities
 - ❑ End Effectors to improve capture and tool performance
 - ❑ Autonomous rendezvous and capture algorithms
 - ❑ Advanced simulation for testing and training
 - ❑ Environmental control to allow extended duration activities
 - Thermal enablers
 - Use of smart composite materials to improve performance

Near Term Activities:

- DTO for refueling capability demonstration on ISS in preparation
- Efforts underway to develop specific enhancing technologies
 - ❑ Material tests in process
 - ❑ Demos in development
 - ❑ Simulation methods improving